Spacetime & Substance, Vol. 3 (2002), No. 3 (13), pp. 97–103

THE CREATION OF TIME FROM SUBSTANCE AND SPACE

Scott M. Hitchcock[1]

Institute for Time and Information Studies 2479 Shawnee Trail Okemos, Michigan, USA 48864

Received July 04, 2002

The 'problem of time' can be 'solved' by observing that 'time' is a computational artifact originating from the 'change' in the states and configurations of substance (matter) at all scales and levels of complexity in the space of an evolving Universe. 'Change' results from instabilities in the configurations of matter, which are driven by the fundamental forces into more stable configurations. The reconfiguration processes resulting in the hierarchical forms of matter throughout the universe are the fundamental sources of 'signals', which carry 'information' from one material system to another. The process of pairing signals, from one changing system (a standard clock) to 'observed' signals from another changing system, creates 'time labeled' information states or 'infostates'. The difference between the time labels for any two infostates is defined as the 'time' elapsed between the two observed events. 'Time' does not exist a priori, but is in fact a computed measure of change. The 'logic' involved in producing time labeled infostates is illustrated using a 'T-computer' model. The construction of a 'direction' and 'dimension' for 'arrows of time' follows from the 'time differences' between labels for the time labeled 'infostates'. The set of all time labeled infostates forms the basis for conventional 'time' coordinates.

1. Is There a 'Problem of Time'?

"Why is the flow of psychological time identical with the direction of increasing entropy? The answer is simple: Man is part of nature, and his memory is a registering instrument subject to the laws of information theory. The increase of information defines the direction of subjective time. Yesterday's experiences are registered in our memory, those of tomorrow are not, and they cannot be registered before tomorrow has become today. The time of our experience is the time which manifests itself through a registering instrument. It is not a human prerogative to define a flow of time; every registering instrument does the same. What we call the time direction, the direction of becoming, is a relation between a registering instrument and its environment; and the statistical isotropy of the universe guarantees that this relation is the same for all such instruments, including human memory." — Han Reichenbach [1].

What is time? Time is a form of *information* [2] that represents a *measure* of *change* [3]. If nothing *changes*, then 'time' has no meaning. 'Change' in the shape, contents, energies, and other physical and chemical properties of substances (matter) forming systems spread throughout the universe is observed as signals originating in or modified by the reconfigurations of these islands on the sea of the vacuum. The reconfigurations are driven by the fundamental interactions of matter with other matter or with the vacuum (space). The problem of time is how do we construct 'time' from change in the universe?

The 'problem of time' can be 'solved' by showing that 'time' is a computational artifact originating from the 'change' in the states and configurations of substance (matter) at all scales and levels of complexity in the space from particles to the galaxy distributions mapping the large scale structure and texture of the evolving Universe [2]. The solution includes a general method of computing time that can apply to the common housefly evading a predator as well as humans attempting to evade the aging process. The T-computer is a general model for physical systems that can take information from signals coming from an observed object in the environment and give them a time label relative to an internal or standard clock. In the simple case of the fly, images are processed and time labeled with respect to the fly's heart rate. They are compared to previously stored (even if only in 'volatile' or temporary memory) images in order to determine an evasive flight path in the fly's 'future'.

This kind of time is relative, non-quantitative and relies on the ordering of the detected signals in a memory. The ordering process creates a kind of time labeling without the need for the normal numbers we associate with the time we read off clocks. The fly needs a primitive sense of time in order to extrapolate the most probable pursuit curve of it prey in order to evade it and survive. Any system that can store information in sequentially ordered sets and compare their relative position with respect to an internal or external standard clock can create 'time' as a measure of what has changed and what might change. The 'problem of

[1] e-mail: hitchco4@pilot.msu.edu

time' can be transformed into a problem of the creation of time by processing the information we gather about the things that change around us and in us.

In this paper I will briefly outline a general model for the creation of *time* from *change*. This may help to explain what *time is*, but it still leaves the question open about the deep nature and origin of 'change'. The 'problem of time' can be solved but it leaves behind a 'problem of change'.

2. Unstable Systems, Change, and Clocks

'Change' results from instabilities in the configurations of matter. These unstable systems or 'clocks' are driven into more stable configurations by the fundamental forces (i.e. strong, electromagnetic, weak and gravitational). If the clock is a quantum system then it is a '**Feynman clock**' or **FC** [2] named after the method of Feynman diagrams. The reconfiguration processes produce the hierarchical forms of matter throughout the universe. During the reconfiguration process signals can be produced. These signals propagate through space carrying 'information' from one material system to another. A clock in this framework is any system that produces or modifies information (signals) during internal processes or through interactive processes with other systems or signals.

3. Signal Detection and Time Labeling

The process of pairing signals, one from a reference system (e.g. a standard clock) and one from an 'observed' system, creates 'time labeled' information states or 'infostates' combining information from both systems. This new infostates is stored in the memory of the observer's information processing system. This computational process in a physical system is a form of time-computer or '*T-computer*'. This is illustrated with a general 'T-computer' model or T-machine (see Figure 1).

The progression of information transfer through the T-computer is mapped by the position of the infostate representing the coupling of the original coincident signals and subsequent 'processed' or computed infostates as they are operated on by sequential 'gates' in the network. This information propagates through the T-computer from the Feynman and Standard clock sources to a time labeled memory. The final calculation of the 'time difference', $\Delta t = t_2 - t_1$, between any two observed events or infostates stored in two different memory locations requires physical 'logic' that can find the 'difference' between the time labels associated with the stored event information. In the following equations the nth composite state, S_n, is listed for the entire T-computer acting as a single quantum system (Figure 1). This state represents a given configuration for the entire system focusing on the 'active' infostate in the causal network. In the following, $|Network_n\rangle = |N_n\rangle$, refers to the 'inactive' collective state of the network components not involved with the location of the 'active' infostate.

The sequence of information flow through a causal network (e.g. T-computer) is tracked by 'active' or 'excited' (e.g. $|FC*\rangle$ infostate representing the spatial location in the network of all the relevant information corresponding to the observed event. The non-active states of the remaining components in the network are summed in the Network0ñ term. The nth (computational) state of the entire T-computer system is S_n. This corresponds to the infostate at a physical gate location in the causal network.

We will assume that the initial configuration of the composite system is given by $|S_n\rangle = |S_0\rangle$, for $n = 0$. The standard clock and the 'observed' system provide the information (signals) to the T-computer detectors through open space or by closed 'circuits' or 'guides'.

We want to remember that we implicitly use another distinct T-computer when we assign a 'start time' for the flow of information through any causal network or T-computer. Since the point here is that 'time' is a bit or qubit of information generated by the T-computer, the start and stop times can be ignored. We will also ignore any 'decoherence' effects on the infostate through its' interaction with the environment (e.g. vacuum) since the decay 'lifetime' of a system due to this coupling is already included in the system start and stop signals processed by the observer. The network will be considered to be robust enough to withstand decay of the local infostate in the active gate or node in the network.

The equations below are intended to illustrate the general features of the T-computer. The details of the physical 'logic' gates and nodes forming a T-computer and the appropriate equations describing them are currently being investigated by the author and will be published at a later date.

We assume that we have an initial configuration of the entire quantum system involving the signal sources, however extended or remote in space, and the causal network forming the T-computer given by the superposition (sum) of all the infostates of the components in the extended system. These are represented by the collective state of the system, S_0, defining a reference 'start' state of the T-computer where the state index is $n = 0$. The following equations represent the state of the entire system in which the 'active' signals, nodes or gates are identified separately from the remainder of the 'inactive' components of the network. This allows us to see how the 'infostate' is created and propagates through the network. We can see how it changes ('expands' with additional qubits into larger qwords or is

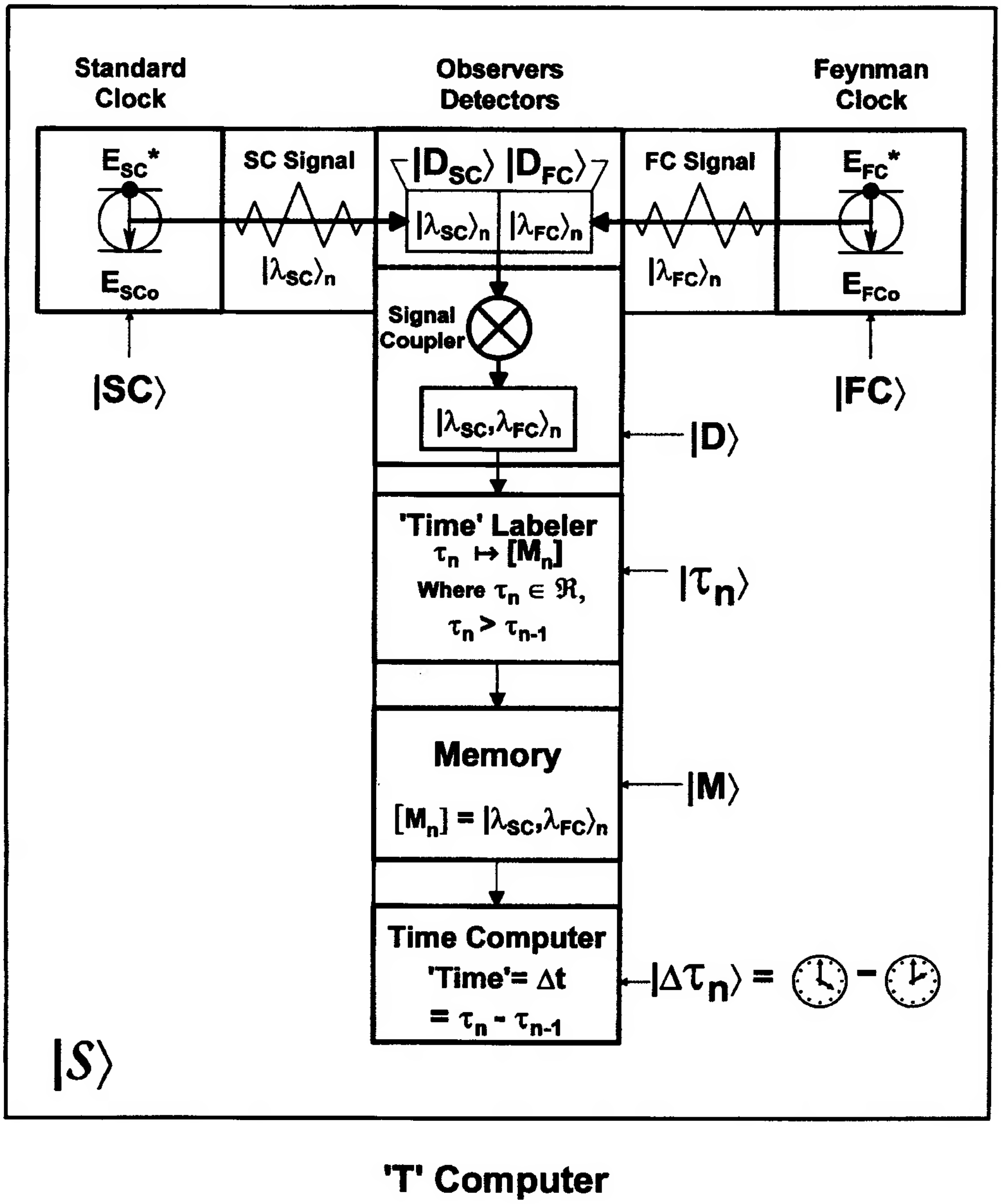

Figure 1: The schematic diagram of a simple idealized T-computer. The functions of the logic 'gates' or nodes and the signals flowing between them represent a general model of the computation of 'time differences' between events in a 'time-independent' information space of 'infostates', $I(S)$, and the system or causal network forming the time labeling computer is in state $|S\rangle$. This state is the collective 'infostate' of the entire network forming the T-computer including the active and inactive components of the relevant computational network. The intent of modeling a T-computer is to show two things. First is that 'time' is a computational artifact of a signal mapping process that defines time as function of the coincidence a clock signal with an event signal. Second is that the T-computer is a component or sub-network of more complex information processing systems. The T-computer is essentially a quantum computer with classical 'time' as an output. The principles in the signal mapping process also apply for larger scale systems that can be treated by classical methods. The key is that all the information used to define time at the macroscopic scale is traceable backwards to the origin of information in the microscopic 'quantum' world.

'reduced' to the selected information needed for a time computation) as it is acted upon by the 'logic' of the network.

The active components (e.g. signals, 'nodes' or 'gates') of the T-computer system (i.e. the 'current' location of relevant information from the 'observed and time labeled' expanded infostate including additional qubits form any extra information created by processing or logic activities on the incoming infostate) and the remainder 'inactive' network for the start state is given by states in Dirac notation.

We begin with the initial state of the T-computer:

$$|FC^*\rangle + |D\rangle + |SC^*\rangle + |N_0\rangle . \tag{1}$$

The active (excited) states of the FC and SC are direct product states of their respective 'ground' states and the 'potential' outgoing signal. They are initially entangled until full decay at which point they become a 'distinct' linear superposition of quantum systems. When the source and its signal become 'measurably distinct' we can consider them to be 'classically' separated. This 'separation' is represented as a sum $(+)$ rather than the direct product $(\otimes)$.

The causal network forming the T-computer is a 'quantum' system. 'Classical properties' of a network are the result of mesoscopic or macroscopic collective excitations or behaviors resulting from the composite collective interactions of the quantum sub-systems or sub-networks. The distinction between quantum and classical scale phenomena is mainly a matter of the observers' choice of what is to be observed. For example, one could measure the 'classical' temperature of a gas cell (a 'thermodynamic' infostate) or the optical scattering of individual 'quantum' photons by the particles in that same gas cell (quantum causal network infostates). The total system is neither quantum or classical alone, but a system with both quantum and classical infostates at various hierarchical levels of complexity.

We note that the Dirac notation lends itself to an oversimplified 'compact' representation of the state of a system considered to have a distinct quantum identity. We neglect the interactions of components of the system with each other or the environment if they are not 'active'. 'Active' components are defined by the 'attention' interaction of the observer with the T-computer. This interaction is the result of an ongoing coupling or feedback between the information source, a standard clock and the observer.

The superposition of the quantum states or the quantum components of an ensemble system represents a system that does not support or generate collective excitations as the result of a 'condensate' state. The condensate state of an n-body system that generates or supports collective excitations is the result of the coupling of all the components in such a way that they are more than a superposition. The expression of this collective or entangled condensate is the direct product of the system states whose whole is clearly more that the sum (superposition) of the parts.

$$[|FC^*\rangle \to |FC_0\rangle \otimes |\lambda_{FC}\rangle] + |D\rangle$$
$$+ [|SC^*\rangle \to |SC_0\rangle \otimes |\lambda_{SC}\rangle] + |N_1\rangle .$$

The decay rates of the FC and the SC may be different. We will assume that the detector will 'hold' the FC infostate until the next available signal arrives from the standard clock. When both signals are detected they are converted into a 2-qubit infostate.

$$[|FC_0\rangle \otimes |\lambda_{FC}\rangle \to |FC_0\rangle + |\lambda_{FC}\rangle]$$
$$+ |D\rangle + [|SC_0\rangle \otimes |\lambda_{SC}\rangle \to |SC_0\rangle + |\lambda_{SC}\rangle] + |N_2\rangle .$$

The collective state of the total system is one in which the 'signals' are in transit to the detector while the rest of the network is in its 'ground' or signal detection 'ready' configuration. Once the 'classical' or spatially distinct signals become close enough to their targets to become superimposed and then entangled with the detectors, their identity as quantum signals traveling 'classically' through space is destroyed. They are now coupled to the detectors as indicated by the direct product of the infostates of the active front-end components of the T-computer.

The 'inactive' components of the network including the FC source and the SC 'time pulse generator' are lumped into the superimposed subset of the systems causal network as represent in the last term below. The 2-channel detector is now in a collective excitation state in which two q-words (or qubits) are stored in parallel quantum registers.

$$[|D\rangle + |\lambda_{FC}\rangle + |\lambda_{SC}\rangle \to |D\rangle \otimes |\lambda_{FC}\rangle \otimes |\lambda_{SC}\rangle]$$
$$+ [|FC_0\rangle + |SC_0\rangle + |N_2\rangle \to |N_3\rangle]$$
$$= |D\rangle \otimes |\lambda_{FC}\rangle \otimes |\lambda_{SC}\rangle + |N_3\rangle .$$

The composite infostate of the detector is an expanded 'q-word' with two q-words concatenated into a larger q-sentence. The q-sentence infostate can now be propagated along the network for used as a 'time stamp' for the 'event' originating in the FC and labeled by the SC.

$$|D\rangle \otimes |\lambda_{FC}\rangle \otimes |\lambda_{SC}\rangle$$
$$+ |N_3\rangle \to |D^*\rangle + |N_{3\to 4}\rangle = |D^*\rangle + |N_4\rangle .$$

The detector infostate is now given a 'label' that will be used later to compute the 'elapsed time' between events in memory or the coordinate 'time' used in standard space-time.

$$|D^*\rangle \otimes |\tau_n\rangle + |N_4\rangle \to |M_k, t_k\rangle$$

$$+ |D\rangle + |N_4\rangle \to |M_k, t_k\rangle + |D\rangle + |N_{4\to 5}\rangle$$

$$= |M_k, t_k\rangle + |D\rangle + |N_5\rangle\,.$$

At this point a signal from another memory location carrying the 'time label' information is shifted into the comparator.

$$[|M_{k+m}, t_{k+m}\rangle + |M_k, t_k\rangle] + |N_6\rangle\,. \tag{2}$$

The 'time labels' are qubits in the n-bit word representing the infostates for the processed information from the source and standard clock 'events' stored in the various addressable memory locations.

$$[|M_{k+m}, t_{k+m}\rangle \otimes |M_k, t_k\rangle]$$

$$+ |N_6\rangle \to |M_{k+m}, t_{k+m}, M_k, t_k\rangle + |N_7\rangle\,.$$

The interaction of the infostates from the two memory locations takes place in a logic gate that compares the 'time' qubits via a 'subtraction' operation. This follows from the same kind of logic used in conventional computers that address specific bits needed for a logic operation involved with finding time differences for time labeled events.

$$|M_{k+m}, t_{k+m}, M_k, t_k\rangle$$

$$+ |N_7\rangle \to |M_{k+m}, M_k, (t_{k+m}, t_k)\rangle + |N_7\rangle \to$$

$$|M_{k+m}, M_k\rangle \otimes |t_{k+m}, t_k\rangle$$

$$+ |N_{7\to 8}\rangle \to |M_{k+m}, M_k\rangle \otimes |\Delta t_n\rangle + |N_8\rangle\,.$$

The processing of the time labels for infostates corresponding to two events results in a 'time' infostate whose information 'content' is the difference between the labels. We are assuming that real numbers are used here, but complex numbers or any other set of number-like labels may work as long as the physical states of the register in which the computed 'time' can be translated into other higher order languages that 'interpret' causal relationships between events.

$$[|M_{k+m}, M_k\rangle \otimes |\Delta t_n\rangle] + |N_8\rangle \to |\Delta t_n\rangle$$

$$+ [|M_{k+m}, M_k\rangle + |N_8\rangle] \to |\Delta t_n\rangle + |N_9\rangle\,.$$

The information encoded in the difference between two time labels for two events is extracted by logic that can evaluate the absolute value of the difference between the two event 'times' resulting typically in a real number. These time label numbers may be physical states such as the number and polarity of charges, analog voltages, discrete binary sets of voltages, polarization states, or spin states. The numerical difference between two time labels corresponds to the physical difference between their physical states in the tubit location of the infostate qword. The physical comparison of two states by the logic of the gate in the T-computer results in the following creation of another physical state in a register that can be translated into a number by higher order information processing:

$$|\Delta t_n\rangle + |N_9\rangle \to [T[|\Delta t_n\rangle] = \Delta t_n = t_{classical}] + |N_{10}\rangle\,.$$

Where 'I' is the computers 'time infostate' resulting from the computation of the time label differences in two event infostates by the time operator, T, acting on the two-qubit infostate, $|\Delta t_n\rangle$, extracted from two memory locations. The action on this state results in conventional time, $T[|\Delta t_n\rangle] = \Delta t_n$. This is the time difference 'magnitude' between events stored in memories (k) and $(k+m)$ with respect to a standard clock.

The **constructed** *equation of time representing the* **bridge** *between quantum and classical processes is:*

$$T[|\Delta t_n\rangle] = \Delta t_n = t_{classical}\,. \tag{3}$$

'Time' differences and the information defining the order of infostates representing the observed events can be used to create temporal pointers or 'arrows of time' between 'earlier' and 'later' infostates (i.e. (k) and $(k+m)$ respectively). This is the 'output' of the T-computer.

The magnitude of the differences in the time labels along with the 'pointer' are used to construct arrows of time and the 'dimension' and 'direction' of the time axis in standard $(3+1)$ space-time. This is the 'classical' time that is generally used as the time 'variable' in standard physics equations of motion.

The real number time differences coupled with the loading of info-states in memory locations, M_{k+m} and M_k along with the set of all ordered events defines for the observer a 'timeline', time 'direction' and time 'dimension' (usually = '1') coupled to a standard 3-space resulting in a $(3+1)$ space-time. It also defines a Quantum Arrow of Time (QAT) for signal creation and induced infostates in detectors originating in the irreversible reconfiguration of unstable 'excited' states. 'Classical Arrows of Time' or CATs are built on collective or generalized information flow in composite quantum systems acting with behaviors that can be described by classical equations of physics and pointing from unstable system configurations to more stable ones.

Quantum information encoded as qubits and qwords are the 'contents of 'infostates' resident in gates, registers and memories. Collections of memories can support many qwords as single information objects. They may be extended quantum objects with serial (sequential excitation network or SEN) properties or collective properties (collective excitation networks or CENs). Combinations of qwords acting like a single quantum object can form qsentences. These various information structures are physical 'infostates' of the signals

or gates in which they reside. The transfer of physical objects combined with their information content defines causal networks and T-computers. The information flow in the universe occurs without any explicit dependence on time as a 'dimension'. Real and complex numbers, or any ordered set of objects can be used to 'time label' events. Unusual units of time can also be created to represent causal relationships in theoretical physics models where complex processes involve 'mixing' of spatio-temporal information as long as their 'ordering' is understood.

Recognition that 'time' is created by complex systems capable of 'computing' it, may clear up 'time' related paradoxes and issues related to causality, information theory, and the 'experience' of time inside complex states of 'consciousness'.

4. Universal Time

Let us now look at a general approach to incorporating time into the space-time constructions used in physical theories to model the evolution of the substances or physical systems in space. The form of the space-time infostate *locating* a physical system, S_J, *in* the most general $(s+\tau)$ *dimensional* space-time topology (*model* of the universe) is given by:

$$|\mathbf{S_J}\rangle_{space-time} = |s - space\rangle \otimes |\tau - time\rangle$$
$$= |d_1, d_2, d_3, ...d_s\rangle \otimes |t_1, t_2, ...t_\tau\rangle$$
$$= |d_1, d_2, d_3, ...d_s, t_1, t_2, ...t_\tau\rangle .$$

Where d_i and t_j are the observable infostates of the system with respect to the ordered 'set' of s space and τ time dimensions of the topological model being used. Note that the time coordinates are really time labels tagged to the event or its infostate associated with the configuration of system S_J. The space coordinates are also 'tagged' onto the infostate identified with this observed system. The infostate for a 'classical' system in standard $(3+1)$ space-time is a sub-space-time of the most general space-time above. This is:

$$|\mathbf{S_{3+1}}\rangle = |d_1, d_2, d_3, t_1\rangle = |x, y, z, t\rangle . \tag{4}$$

This state is the *space-time information component* of a more general *complete infostate* that contains not only the space-time location information but also all other possible total energy, internal configuration, material composition and environmental information. This is represented by I(total energy, configuration, composition, ..., etc.)=I(other). This term implicitly contains all the information about the all the physical subsystems forming the composite or collective state of the substance (complex system) being observed. It is important to clearly identify the processes of information mapping to the various coordinates and to have inverse functions that take one back to standard 3+1 space-times as *dimensional* information is gained or lost in the modeling process.

The complete infostate for this system is:

$$|\mathbf{S_J}\rangle_{complete} = |I(other)\rangle \otimes |d_1, d_2, ..., d_s\rangle \otimes$$
$$|t_1, t_2, ..., t_\tau\rangle = |I(other), d_1, d_2, ..., d_s, t_1, t_2, ..., t_\tau\rangle$$
$$= |I(other), space, time\rangle .$$

This is the **complete infostate** for the system relative to the rest of the universe. The infostate for a given configuration, α, of universe, $|\mathbf{U}\rangle_\alpha$, is then the direct product of all the infostates of the substances and space of which it is composed. We have the following equation for the α-th state of the universe with all its subsystems in their α-th states:

$$|\mathbf{U}\rangle_\alpha = |Vacuum\rangle_\alpha \bigotimes \left[\bigotimes_{J=1}^{\infty} |S_J\rangle_\alpha \right] . \tag{5}$$

This is the form of *time-independent* states of the universe that one can use in the Wheeler-DeWitt equation. The transition from one configuration to another forms a 'history' of the universe composed of a sequence of configuration changes. Cosmic 'time' is the result of 'change' not in time, but change creating information that becomes 'time' when signals are processed by observers inside the evolving universe. The transition from the (i) to the $(i+1)$ states results in the creation of information that computes into the time elapsed between those two states.

5. Computing Time

The computation of the difference between the time labels for any two infostates results in another 'bit' of information that we call the 'time' elapsed between the two observed events. From this perspective, 'time' does not exist a priori, but is in fact a computed measure of change. The construction of a 'direction' and 'dimension' for 'arrows of time' follows from the ordered sets of numbers or label states added to observed 'infostates' originating in unstable systems.

6. The Substance of Time

A general topology of time can be built from this approach that encompasses convenient theoretical constructions like 'imaginary' time, various 'arrows of time', and multiple or partial time coordinates used in higher dimensional topological models of the physical universe. Time is real in the same sense that information is real. The 'substance' of 'time' is 'change'.

7. Summary

In this brief paper I have attempted to outline a new way of thinking about time. I would like to summarize by stating the following three conclusions.

1. Change in the configurations of substance in space creates signals carrying information about their sources to other systems in space.

2. Signals are computed into *time* labels for infostates representing observed phenomena.

3. Time is used to construct space-time maps of the evolving universe and along with application of the laws of physics, a determination of the possible emerging configurations of matter can be 'computed'.

There is much more work to be done to detail how real physical systems compute time and how this new approach to time can be understood in the context of information theory applied to quantum and classical systems, causal networks, collective excitations and behaviors of complex systems, and consciousness.

References

[1] **"The Direction of Time"** by *Hans Reichenbach*, Edited by Maria Reichenbach, Dover Publications, Inc., Mineola, NY, 1999.

[2] **"Time and Information: From Feynman Diagrams to Feynman Clocks and Beyond"**, by *Scott M. Hitchcock*. An invited talk and paper given at the 'XXIV International 'Time' Workshop on the Fundamental Problems of High Energy Physics and Field Theory' at the Institute for High Energy Physics (IHEP), Protvino, Russia, June 27-29, 2001. Published in the Proceedings of the IHEP Workshop, also available at LANL http://xxx.lanl.gov/abs/quant-ph/0111025.

[3] **"The End of Time; the Next Revolution in Physics"**, by *Julian Barbour*, Oxford University Press, UK 1999.